

February 17, 1887.

Professor STOKES, D.C.L., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read :—

- I. "A Record of Experiments upon the Functions of the Cerebral Cortex." By VICTOR HORSLEY, M.B., F.R.C.S., F.R.S., Professor Superintendent of the Brown Institution, and EDWARD ALBERT SCHÄFER, F.R.S., Jodrell Professor of Physiology in University College, London. (From the Physiological Laboratory of University College.) Received February 5, 1887.

(Abstract.)

The paper consists, as its title implies, of a record of experiments relating to the functions of the cerebral cortex, a subject upon which the authors have been engaged during three years. The experiments have been entirely made upon monkeys. After describing the methods employed, the general results of excitation and of extirpation of various parts of the cerebral hemispheres on one or both sides are given, and the cases in which the method of ablation has been employed are then recorded in detail, the symptoms observed during life and the condition of the brain after death being systematically noted. Each case is illustrated by one or more drawings, showing the exact condition of the brain *post mortem*. In some instances sections of the brain are also represented. The paper includes also a topographical plan of the excitable or motor region of the *cortex cerebri*.

- II. "On Radiant Matter Spectroscopy:—Examination of the Residual Glow." By WILLIAM CROOKES, F.R.S., V.P.C.S. Received February 10, 1887.

The duration of phosphorescence after cessation of the exciting cause is known to vary within wide limits of time, from several hours in the case of the phosphorescent sulphides to a minute fraction of a

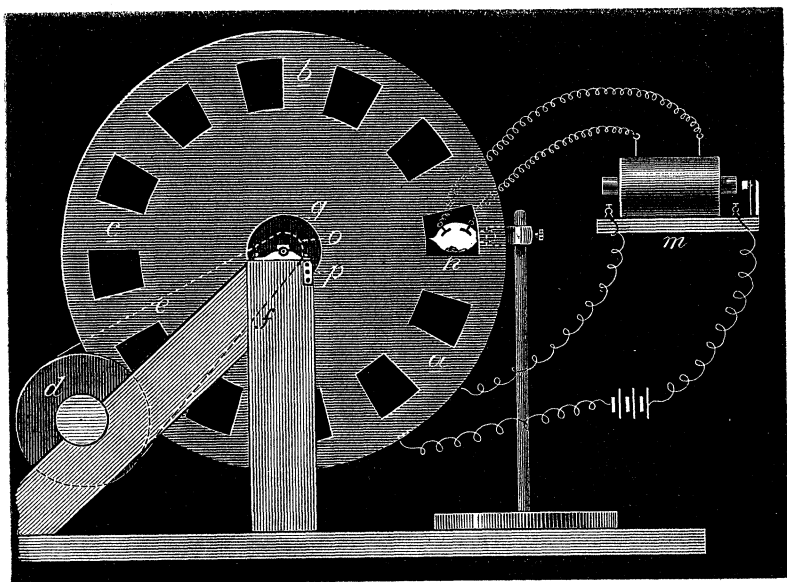
VOL. XLII.

I

second with uranium glass and sulphate of quinine. In my examinations of the phosphorescent earths glowing under the excitement of the induction discharge in vacuo, I have found very great differences in the duration of the residual glow. Some earths continue to phosphoresce for an hour or more after the current is turned off, while others cease to give out the light the moment the current stops. Having succeeded in splitting up yttria into several simpler forms of matter differing in basic power,* and always seeking for further evidence of the separate identity of these bodies, I noticed occasionally that the residual glow was of a somewhat different colour to that it exhibited while the current was passing, and also that the spectrum of this residual glow seemed to show, as far as the faint light enabled me to make out, that some of the lines were missing. This pointed to another difference between the yttrium components, and with a view to examine the question more closely I devised an instrument similar to Becquerel's phosphroscope, but acting electrically instead of by means of direct light.

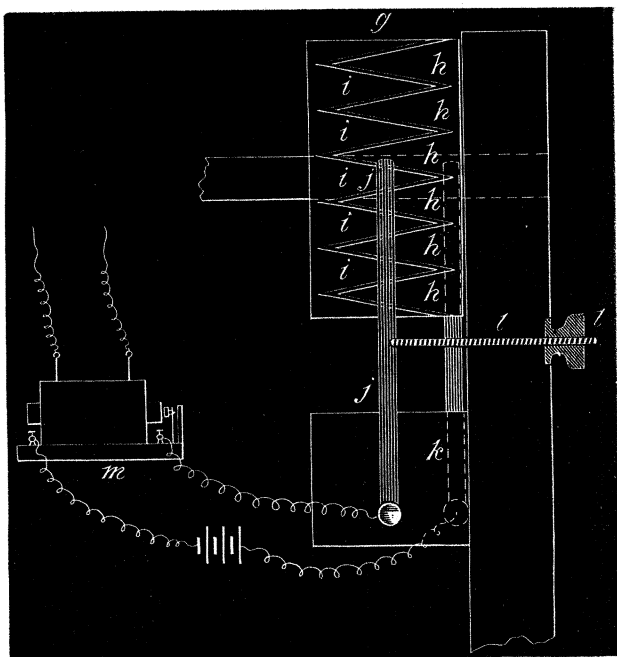
The instrument, shown in fig. 1, A and B, consists of an opaque disk, *a b c*, 20 inches in diameter, and pierced with twelve openings near the edge as shown. By means of a multiplying wheel, *d*, and

FIG. 1, A.



* 'Roy. Soc. Proc.,' vol. 40, pp. 502-509 (June 10, 1886).

FIG. 1, B.



band, $e f$, the disk can be set in rapid rotation. At each revolution a stationary object behind one of the apertures is alternately exposed and hidden twelve times. A commutator, g (shown enlarged at fig. 1, B), forms part of the axis of the disk. The commutator is formed of a hollow cylinder of brass round a solid wooden cylinder. The brass is cut into two halves by a saw cut running diagonally to and fro round it, so as to form on each half of the cylinder twelve deeply cut teeth interlocking, and insulated from these on the opposing half cylinder by an air space about 2 mm. across. Only one half $h h h$, of the cylinder is used, the other, $i i i$, being idle; it might have been cut away altogether were it not for some little use that it is in saving the rubbing-spring, j , from too great friction when passing rapidly over the serrated edge. To a block beneath the commutator are attached two springs, one, k , rubbing permanently against the continuous base of the serrated hemicylinder, $h h$, and the other, j , rubbing over the points of the teeth of $h h$. By connecting these springs with the wires from a battery it will be seen that rotation of the commutator produces alternate makes and breaks in the current. The spring, j , rubbing against the teeth is made with a little adjustment sideways, so that it can be said to touch the points of the teeth only,

when the breaks will be much longer than the makes, or it can be set to rub near the base of the teeth, when the current will remain on for a much longer time and the intervals of no current will be very short. By means of a screw, *ll*, attached to the spring, any desired ratio between the makes and the breaks can be obtained. The intermittent primary current is then carried to an induction coil, *m*, the secondary current from which passes through the vacuum tube, *n*, containing the earth under examination. When the commutator, the coil-break, and the position of the vacuum tube are in proper adjustment, no light is seen when looked at from the front if the wheel is turned slowly (supposing a substance like yttria is being examined), as the current does not begin till the tube is obscured by an intercepting segment, and it ends before the earth comes into view. When, however, the wheel is turned more quickly, the residual phosphorescence lasts long enough to bridge over the brief interval of time elapsing between the cessation of the spark and the entry of the earth into the field of view, and the yttria is seen to glow with a faint light, which becomes brighter as the speed of the wheel increases.

To count the revolutions, a projecting stud, *o*, is fastened to the rotating axis, and a piece of quill, *p*, is attached to the fixed support, so that at every revolution a click is produced. With a chronograph watch it is easy in this way to tell the time, to the tenth of a second, occupied in ten revolutions of the wheel.

Under ordinary circumstances it is almost impossible to detect any phosphorescence in an earth until the vacuum is so high that the line spectrum of the residual gas begins to get faint; otherwise the feeble glow of the phosphorescence is drowned by the greater brightness of the glowing gas. In this phosphoroscope, however, the light of glowing gas does not last an appreciable time, whilst that from the phosphorescent earth endures long enough for it to be caught in the instrument. By this means, therefore, I have been able to see the phosphorescence of yttria, for example, when the barometer gauge was 5 or 6 mm. below the barometer.

When the earth under examination in the phosphoroscope is yttria free from samaria, and the residual emitted light is examined in the spectroscope, not all the bands appear at the same speed of rotation. At a slow speed the double greenish-blue band of $G\beta$ (545) first comes into view, closely followed by the deep blue band of $G\alpha$ (482). This is followed, on increasing the speed, by the bright citron band of $G\delta$ (574), and at the highest speed the red band of $G\zeta$ (619) is with difficulty seen.

The following are measurements of the time of duration of the phosphorescences of the different constituents of yttrium. The wheel was first rotated slowly, until the first line visible in the spectroscope attached to the phosphoroscope appeared; the speed was counted,

and it was then increased until the line next visible was seen. In this way the minimum speed of revolution necessary to bring each line into view was obtained, and from these data the duration of phosphorescence for each constituent of yttria was calculated. The time in the following table represents in decimals of a second the time elapsing between the cessation of the induction discharge and the visibility of the residual glow of the earth :—

At 0·0035 sec. interval	the green and blue lines of $G\beta$ and $G\alpha$ begin to be visible.
At 0·0032 ,,	the citron line of $G\delta$ begins to be visible.
At 0·00175 ,,	the deep red line of $G\zeta$ (647) is just visible.
At 0·00125 ,,	the line of $G\delta$ is almost as bright as that of $G\beta$, and the red line of $G\gamma$ is visible.
At 0·000875 ,,	the highest speed the instrument could be revolved with accuracy, the whole of the lines usually seen in the yttria spectrum could be seen of nearly their usual brightness.

I have already recorded* that phosphate of yttria, when phosphoresced in vacuo, gives the green lines very strongly whilst the citron band is hazy and faint. The same tube of yttric phosphate was now examined in the phosphoroscope. The green lines of $G\beta$ soon showed themselves on setting the wheel into rapid rotation, but I was unable to detect the citron band of $G\delta$ even at a very high speed.

The effect of calcium on the phosphorescence of yttria and samaria has been frequently referred to in my previous papers. It may save time if I summarise the results here. About 1 per cent. of lime added to a badly phosphorescing body containing yttrium or samarium always causes it to phosphoresce well. It diminishes the sharpness of the citron line of $G\delta$ but increases in brightness. It also renders the deep blue line of $G\alpha$ extremely bright. The green lines of $G\beta$ are diminished in brightness. Lime also brings out the phosphorescence of samarium, although by itself, or in the presence of a small quantity of yttrium, samarium scarcely phosphoresces at all.

In the phosphoroscope the action of lime on yttrium is seen to entirely alter the order of visibility of the constituents of yttrium. In a mixture of equal parts yttrium and calcium, the citron $G\delta$ line is the first to be seen, then comes the $G\alpha$ blue line, then the $G\beta$ green line, and finally the $G\gamma$ red line. This may, I think, be explained somewhat as follows :—Calcium sulphate has a long residual phosphorescence, whilst yttrium sulphate has a comparatively short residual phosphorescence. Now with yttrium, although the green phosphorescence of $G\beta$ lasts longest, it does not last nearly so long as that of calcium sulphate. The long residual vibrations of the calcium compound induce, in a mixture of calcium and yttrium, phosphorescence in those yttric molecules ($G\delta$) whose vibrations it can assist,

* 'Phil. Trans.,' 1883, Part III (pp. 914—916).

in advance of those ($G\beta$) to which it is antagonistic; the line of $G\delta$ therefore appears earlier in the phosphoroscope than that of $G\beta$, although were calcium not present the line of $G\beta$ would appear first.

Experiments were now tried with definite mixtures of yttria and lime as ignited sulphates, to see where the special influence of lime on $G\delta$ ceased.

Yttrium.	Calcium.	
Per cent.	Per cent.	
97½	2½	Order of appearance in the phosphoroscope.— $G\beta$, $G\alpha$, $G\delta$, and $G\eta$. The citron line of $G\delta$ is only to be seen at a high speed, and is then very faint.
95	5	Order of appearance in the phosphoroscope.— $G\alpha$, $G\beta$, and $G\delta$ (citron and blue) together, and lastly $G\eta$ (red). At a very high speed the green lines of $G\beta$ become far more luminous than any other line.
90	10	Order of appearance.— $G\delta$ and $G\alpha$ together, then $G\beta$, and lastly $G\eta$.
80	20	Order of appearance.— $G\delta$ and $G\alpha$ simultaneously, then $G\beta$, and lastly $G\eta$. The residual phosphorescence last for 30 seconds after the current stops. The light of this residual glow is entirely that of $G\delta$. The line of $G\beta$ comes into view at an interval of 0.0045 second. At 0.00175 second the line of $G\eta$ is just visible.
60	40	} Order of appearance.— $G\delta$ and $G\alpha$ together, then $G\beta$ and $G\eta$ together.
50	50	
40	60	
30	70	
10	90	} Order of appearance.— $G\delta$, $G\alpha$, $G\beta$.
5	95	
1	99	
		Order of appearance.— $G\delta$, $G\alpha$. The green lines of $G\beta$ could not be seen in the phosphoroscope; they would probably be obliterated by the stronger green of the continuous spectrum given by the calcium.

The action of barium on yttrium was now tried. The following mixtures (as ignited sulphates) were made:—

Yttrium.	Barium.	
Per cent.	Per cent.	
95	5	} In the phosphoroscope the $G\beta$ line appears earliest, but the blue $G\alpha$ line is the next to be seen, whilst the red line of $G\eta$ is the latest in appearing. As the percentage of yttrium increases the blue line more and more overtakes the red and increases in brightness.
90	10	
80	20	
70	30	} Spectrum similar to the above. As the percentage of yttrium increases the spectrum grows brighter. In the phosphoroscope the earliest line to appear is the $G\beta$ green, then the $G\eta$ red, and next closely following it the $G\alpha$ blue.
60	40	
50	50	
40	60	
30	70	
25	75	

Yttrium.	Barium.	
Per cent.	Per cent.	
20	80	In the radiant matter tube all these mixtures give similar spectra. The $G\beta$ green is a little brighter and the $G\delta$ citron is a little fainter than in the corresponding mixtures of yttrium and calcium, but the whole of the yttrium lines are seen. In the phosphoroscope the $G\beta$ green is the first to appear, then the $G\eta$ red. The $G\delta$ citron is not visible at any speed.
15	85	
10	90	
5	95	
1	99	Red line of $G\eta$ is much brighter; $G\delta$ is very faint, and the green of $G\beta$ is stronger. In the phosphoroscope the order of appearance is,—first the line of $G\beta$, then the red line of $G\eta$.
0.5	99.5	Phosphoresces with difficulty, of a light blue colour, but turns brick-red in the focus of the pole. Spectrum very faint. Order of appearance to phosphoroscope :— $G\beta$ first, the others too faint to be seen.

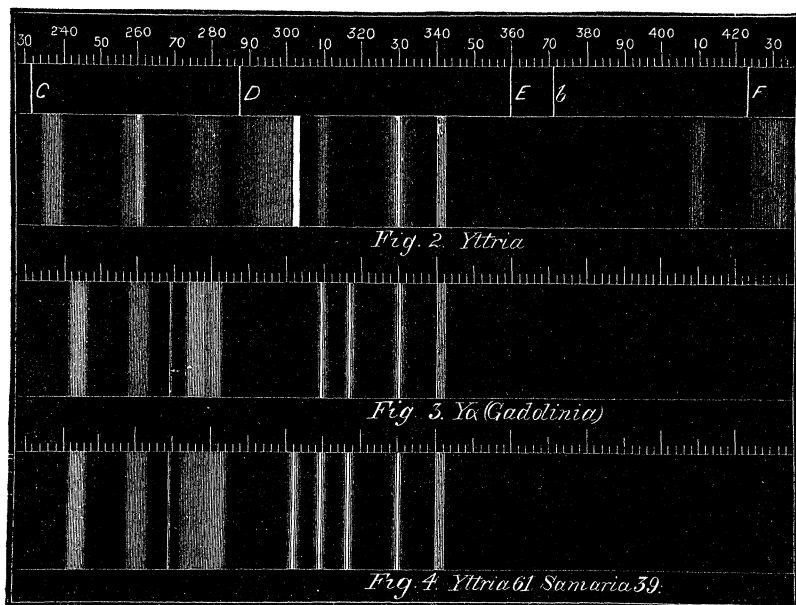
The next experiments were tried with strontium, to see what modification the addition of this body to yttrium would produce. The following mixtures of ignited sulphates were experimented with :—

Yttrium.	Strontium.	
Per cent.	Per cent.	
95	5	A very good yttrium spectrum. In the phosphoroscope the order of appearance is—First the green of $G\beta$, then the $G\alpha$ blue, lastly the $G\eta$ red. No $G\delta$ citron line could be seen.
80	20	In the phosphoroscope the green of $G\beta$ is very prominent at a low speed, standing out sharply against a black background. With a higher velocity the $G\alpha$ and $G\eta$ lines come into view.
60	40	The ordinary spectrum of this and the neighbouring mixtures is very rich in the citron line of $G\delta$, but I entirely fail to see a trace of this line in the phosphoroscope at any speed. The line of $G\beta$ is the first to come, then the blue line of $G\alpha$.
40	60	
35	65	At about this point a change comes over the appearance in the phosphoroscope. The blue line of $G\alpha$ is now the earliest to appear, and it is followed by the $G\eta$ red and $G\beta$ green. No $G\delta$ line is seen.
25	75	These mixtures are very similar to each other in the phosphoroscope. The line of $G\alpha$ comes first, next the $G\eta$ line, then $G\beta$ line. No $G\delta$ citron line has been seen in any of these mixtures.
15	85	
5	95	
0.5	99.5	

In a paper read before the Royal Society, June 18th, 1885*, I described the phosphorescence spectrum given by a mixture of

* 'Phil. Trans.,' 1885, Part II (p. 716).

61 parts of yttrium and 39 parts of samarium, and illustrated it by a coloured lithograph. Also in a paper read before the Royal Society, February 25th, 1886,* I described and figured the phosphorescent spectrum of an earth obtained in the fractionation of yttria which was identical, chemically and spectroscopically, with an earth discovered by M. de Marignac, and provisionally called by him $Y\alpha$. I repeat here these spectra, with the spectrum of yttrium added for comparison. Omitting minor details, it is seen that the $Y\alpha$ spectrum



is identical with that of the mixture yttrium 61, samarium 39, with one important exception—the citron line of $G\delta$ in the former spectrum is absent in the latter. Could I by any means remove $G\delta$ from the mixture of yttrium and samarium the residue would be $Y\alpha$. I have little doubt that this will soon be accomplished, but in the meantime the phosphoscope enables us to remove the line of $G\delta$ from the mixture. It is only necessary to add strontium to a suitable mixture of yttrium and samarium and view the phosphorescing mixture in the instrument when the wheel is rotating rapidly, to obtain a spectrum which is indistinguishable from that of $Y\alpha$.

In the search for bodies giving discontinuous phosphorescent spectra I have submitted a great number of earths and combinations

* 'Roy. Soc. Proc.,' vol. 40, p. 236.

to the electric discharge in vacuo, and have noted the results. As the superficial phosphorescence apart from the composition of the emitted light has formed the subject of several recent papers by my friend M. Lecoq de Boisbaudran, before the Académie des Sciences, it may be useful if I place on record some of the more striking facts which have thus come under my notice. The bodies are arranged alphabetically, and, unless otherwise explained, were tested in the radiant matter tube in the form of ignited sulphates.

Alumina, in any of the forms which give the crimson line ($\lambda 6942-6937$) has a very persistent residual glow. In the phosphoroscope rubies shine with great brilliancy. This phosphorescence of alumina has recently been the subject of a paper read before the Royal Society.*

Antimony oxide with 95 per cent. of lime (in the form of ignited sulphate). White phosphorescence, the spectrum showing a broad space in the yellow, cutting the red and orange off. In the phosphoroscopes the residual glow is very strong, and of a greenish colour. The spectrum of the residual light shows that the red and orange are entirely obliterated, leaving the green and blue very luminous. Antimony oxide with 99 per cent. of lime gives a pale yellowish phosphorescence, which on heating turns red. In other respects it is like the 5 per cent. mixture.

Arsenious acid with 99 per cent. of lime gives a greenish-white phosphorescence like pure calcium sulphate.

Barium 5 per cent., calcium 95 per cent.—The sulphates phosphoresce green, with specks of yellow and violet. The spectrum is continuous, with slight concentration in the red, great concentration in the green, and in the orange a broad black band hazy at the edges.

Bismuth 15 per cent., calcium 85 per cent., phosphoresces of a bright reddish-orange. The spectrum shows a tolerably sharp and broad dark band in the red and orange, and a strong concentration of light in the green and blue; the spectrum being continuous and divided into two parts by a black band in the yellow, as in the case of the antimony-calcium spectrum. In the phosphoroscope the red and orange disappear and the green and blue remain. Bismuth 7 per cent., calcium 93 per cent.—The action is similar to the 15 per cent. mixture, except the colour of the phosphorescence, which is whiter. In the phosphoroscope the red and orange below the dark band is cut off. With 2 per cent. of bismuth the same phenomena occur. With 0.5 bismuth the phosphorescence is greenish-blue and the spectrum is continuous, with strong concentrations in the orange and green. The phosphoroscope cuts off the red and orange.

* 'Roy. Soc. Proc.,' vol. 42, 1887, p. 25.

Cadmium 1 per cent., calcium 99 per cent.—Similar to calcium sulphate, *q. v.*

Calcium sulphate was prepared from a colourless and transparent rhomb of Iceland spar which had been used for optical purposes. It was dissolved in nitric acid, the nitrate was decomposed with distilled sulphuric acid, and the ignited sulphate tested in the tube. The phosphorescence is bright greenish-blue without bands or lines. In the phosphoroscope the colour is a rich green; the spectrum shows the red and orange entirely cut off, leaving the green and blue; the blue is especially strong.

Calcium sulphates prepared from Professor Breithaupt's calcites* were re-examined. All phosphoresce with the normal greenish-blue glow of calcium, except No. 11, which gives a reddish glow. A minute trace of samarium was found in this calcite, but not enough to affect the colour of the glow. In the phosphoroscope all the specimens give a continuous spectrum beyond the yellow, the red and orange being cut off as usual.

Chromium 5 per cent., calcium 95 per cent., as sulphates, gives a pale reddish phosphorescence. In the phosphoroscope the colour is green, and the red and orange are cut off. 1 per cent. of chromium with calcium phosphoresces green in the cold, and becomes a red when slightly heated. The behaviour of chromium with aluminium has already been described.†

Copper sulphate with 95 per cent. calcium sulphate behaves like calcium sulphate.

Diamonds phosphoresce of various colours. Those glowing pale blue have the longest residual glow, next come those phosphorescing yellow; I am unable to detect any residual glow in diamonds phosphorescing of a reddish colour. A large diamond of a greenish hue, very phosphorescent, shines almost as brightly in the phosphoroscope as out of it.

Glucina phosphoresces of a rich blue colour. There appears to be no residual glow with this earth in the phosphoroscope.

Lanthanum.—All the specimens of lanthanum sulphate I have examined in the radiant-matter tube phosphoresce of a reddish colour, and give a broad hazy band in the orange, with a sharp line $—1/\lambda^{280}$ —superposed on it. This is identical with the line of Ge, one of the constituents of the samarium phosphorescent spectrum. Calcium added to lanthanum changes the colour of the phosphorescence from red to yellowish, and brings out yttrium and samarium lines, these metals being present as impurities; the $G\delta$ and $G\alpha$ lines are also seen, but the space which should be occupied by the $G\beta$ green is now a dark space. I have shown that when $G\delta$, $G\alpha$, and $G\beta$ are present

* 'Phil. Trans.,' 1885, Part II (p. 697).

† 'Roy. Soc. Proc.,' vol. 42, p. 28, *et seq.*

in very small quantities with lime, the lines of $G\delta$ and $G\alpha$ are intensified, while that of $G\beta$ is weakened. This new result seems to show that if only a small trace of $G\beta$ is present with lime and lanthanum, the green line is not only suppressed, but the quenching action has actually extended so far as to neutralise that part of the continuous lime spectrum having the same refrangibility as the $G\beta$ line, the result being a black space in the spectrum. In the phosphoscope the line of $G\epsilon$ is visible at the slowest speed; $G\delta$ comes in at an interval of 0.0035 second, and the $G\alpha$ line immediately afterwards.

Lead sulphate, by itself, in the radiant-matter tube glows with a nearly white colour, giving a continuous spectrum. In the phosphoscope the red and orange are cut off, leaving a strong concentration of light in the green and blue. 5 per cent. of lead added to calcium sulphate phosphoresces like lime.

Magnesia phosphoresces pink. 5 per cent. with lime, as sulphates, give a greenish phosphorescence, with a tendency to turn red as the powder heats. As the Oriental ruby contains between 1 and 2 per cent. of magnesia, a mixture was prepared of acetate of alumina with 2 per cent. of magnesia, and tested after ignition. It gave no spectrum or lines. This was done to see if the crimson line of aluminium might be due to the presence of magnesia.

Nickel added to calcium sulphate in the proportion of 5 per cent. makes no alteration in the usual phosphorescent phenomena of calcium.

Potassium, 5 per cent., added to calcium sulphate gives a bright phosphorescence, and made the residual glow very persistent.

Samarium.—The phosphorescent behaviour of this body, alone and mixed with other substances, has been fully described in my paper on samarium.*

Scandium, either in the form of earth or sulphate, phosphoresces of a very faint blue colour, but the light is too feeble to enable a spectrum to be seen. Addition of lime does not bring out any lines.

Sodium sulphate mixed with an excess of calcium sulphate gives a greenish tinge to the usual colour of the phosphorescence. The sodium line is visible in the spectrum.

Strontia in the radiant-matter tube glows with a rich blue colour, showing in the spectroscope a continuous spectrum with a great concentration of light in the blue and violet. In the phosphoscope the colour of the glow is bright green, showing in the spectroscope a continuous spectrum, with the red and blue ends cut off. A mixture of calcium sulphate with 5 per cent. of strontium sulphate behaves like calcium sulphate alone.

* 'Phil. Trans.,' 1885, Part II (pp. 709—721).

Thorium, as oxide or sulphate, refuses to phosphoresce, and the tube rapidly becomes non-conducting. A tube with thoria at one end and a phosphorescent earth such as lime or yttria at the other end, and furnished with a pair of poles near each end, at a particular exhaustion is non-conducting at the thoria end, while it conducts at the yttria end. If the wires of the induction coil are attached to the poles at the thoria end, no current will pass; rather than pass through the tube, the spark prefers to strike across the spark gauge—a striking distance of 37 mm.—showing an electromotive force of 34,040 volts. Without doing anything to affect the degree of exhaustion, on transferring the wires of the induction coil from the thoria to the yttria end, the spark passes at once. To balance the spark in air the wires of the gauge must be made to approach till they are only 7 mm. apart, equivalent to an electromotive force of 6440 volts; the fact of whether thoria or yttria is under the poles making a difference of 27,600 volts in the conductivity of the tube. The explanation of this action of thoria is not yet quite clear. From the great difference in the phosphorescence of the two earths, it is evident that the passage of the electricity through these tubes is not so much dependent on the degree of exhaustion as upon the phosphorogenic property of the body opposite the poles. This view is supported by the fact that the thoria may be replaced by a metal wire, when the same obstructive action will result.

Lime does not give phosphorescent properties to thoria, if this earth be pure, but it brings out the lines of yttrium and samarium which are almost always present in small quantities in thoria unless it has been specially purified.

Tin with 95 per cent. of lime gives the lime phosphorescence only.

Thulium and *erbium* together phosphoresce with a green light, giving the erbium spectrum already described before this Society.* There is, in addition, a faint blue line apparently double (see “Ytterbium”). The addition of lime causes the mixture to phosphoresce of a pale blue colour. The spectrum now shows a bright blue band, in the same position as the faint double blue band seen in the absence of lime. The blue line of $G\alpha$ is also seen, and a faint line of $G\delta$. The deep red line of $G\eta$, one of the constituents of the ordinary yttria spectrum, is prominent in this spectrum.

Tungsten and *uranium*, each mixed with 95 per cent. of lime, only give the lime spectrum.

Ytterbium.—I have not yet succeeded in preparing this body of trustworthy purity; but through the kindness of Professor Clève, M. de Marignac, and Professor Nilson I have been enabled to experiment with specimens of ytterbia prepared by these chemists.

* ‘Roy. Soc. Proc.’ vol. 40, p. 77, fig. 1 (January 7, 1886).

Professor Clève's ytterbia, in the form of sulphate, gives in the radiant-matter tube a blue phosphorescence, the spectrum of which shows a strong double blue band,* together with traces of the G δ and the erbia green lines. The addition of lime broadens the blue band and makes it single. Professor Clève writes that this ytterbia may contain some traces of thulia, perhaps also of erbia, but scarcely any other impurities. Measurements in the spectroscope give the following approximate results.

Scale of spectroscope.	λ .	$\frac{1}{\lambda^2}$.	Remarks.
8.63	4626	4673	Commencement of first blue line. This edge is very hazy.
8.54	4574	4780	Centre of the first blue line.
8.45	4524	4885	End of first blue line.
8.44	4518	4898	Centre of dark interval between the two blue lines.
8.40	4475	4994	Centre of second blue line. This line is narrower than the first line.

The following are measurements taken with the mixture of this ytterbia and lime :—

Scale of spectroscope.	λ .	$\frac{1}{\lambda^2}$.	Remarks.
8.71	4674	4577	Up to this point there is the continuous spectrum of li-calcium. Here a black space commences.
8.515	4555	4819	Commencement of a hazy blue band.
8.475	4538	4855	End of hazy blue band. This band is of considerable brilliancy.

These blue bands are seen much fainter without lime, and are about as strong in the mixture of thulia and erbia with lime described above. I had ascribed them to ytterbia, when Professor Nilson kindly forwarded me a small specimen of ytterbia, considered by him perfectly pure, and used for his atomic weight determinations. This ytterbia gives absolutely no blue bands. The origin of these bands therefore remains uncertain.

* This is the band spoken of in my Royal Society paper of 9th June last ('Roy. Soc. Proc.,' vol. 40, 1886, p. 507), provisionally called S γ , and ascribed to ytterbia. If it is not due to ytterbia it is evidence of a new body.

Ytterbia from Professor Nilson, in the form of sulphate, refuses to phosphoresce without the addition of lime. When lime is added it only brings out traces of the phosphorescent bands of $G\epsilon$, $G\beta$, and $G\alpha$. Evidently these are impurities.

Ytterbia from M. de Marignac is identical with that from M. Clève, as far as my examination can go. In sending me this ytterbia M. de Marignac warned me that he was very far from thinking it pure.

Yttrium.—During the fractionation of the higher fractions of yttria (+6, 118 and 119), a very sharp green line sometimes makes its appearance, situated between $G\beta$ and $G\gamma$ (approximate position on the $1/\lambda^2$ scale, 325). It is very faint, and is not connected with the orange line of $S\delta$, although it is as sharp. The yttria showing these lines phosphoresces of a transparent golden-yellow colour, the fractions at the other end phosphorescing yellowish green.

I have previously described the action of a large number of bodies on the phosphorescence of samarium.* The experiments resulting in the following observations were tried at about the same time. I will describe them in alphabetical order. Unless otherwise mentioned all the mixtures were in the form of anhydrous sulphates.

Yttrium 5 per cent., *aluminium* 95 per cent., gives a good yttria spectrum; the blue line of $G\alpha$ is very distinct, and the double green of $G\beta$ is well divided. In the phosphoroscope the $G\beta$ and $G\alpha$ lines first appear simultaneously, then the $G\delta$ line.

Yttrium 99.5 per cent., *bismuth* 0.5 per cent.—The spectrum is bright, and on close examination a trace of samarium green, $G\gamma$, is to be detected forming a wing to the $G\delta$ line. In the phosphoroscope the citron line of $G\delta$ entirely disappears and the samarium double green line, which out of the phosphoroscope is almost obscured by the great brightness of $G\delta$, now appears distinctly, together with the green $G\beta$ line. *Yttrium* 95 per cent., *bismuth* 5 per cent., gives the usual yttria spectrum. No $G\delta$ line appears in the phosphoroscope at any speed. At first only the $G\beta$ line is seen, and next the $G\alpha$ line appears, as in yttria. On gradually increasing the percentage of bismuth the spectrum of yttria grows fainter, until with 95 per cent. of bismuth the phosphorescence is bad and the spectrum faint.

Yttrium 5 per cent., *cadmium* 95 per cent., gives a brilliant phosphorescence, but the spectrum is almost continuous. In the phosphoroscope a faint concentration of light is seen in the green, which becomes sharper as the speed increases.

The action of calcium on the phosphorescence of yttrium has already been described.

Yttrium and *cerium*.—Cerium has the effect of deadening the

* "On Radiant Matter Spectroscopy. Part 2—Samarium." 'Phil. Trans,' 1885, Part II (pp. 710—722).

brilliancy of the yttrium spectrum in proportion to the quantity added. All the bands remain of their normal sharpness.

Yttrium 5 per cent., copper 95 per cent., phosphoresces very feebly.

Yttrium 90 per cent., didymium 10 per cent.—This mixture gives a good yttria spectrum. Yttrium 70 per cent., didymium 30 per cent., phosphoresces very fairly and gives all the usual lines.

Yttrium 50 per cent., didymium 50 per cent., refuses to phosphoresce. The tube is either too full of gas to allow the phosphorescence to be seen or it becomes non-conducting. When the mixture is illuminated by the glowing gas the absorption lines of didymium the green are seen. With higher proportions of didymium the same results are produced. On adding 25 per cent. of lime to the mixture containing 50 per cent. of didymium the yttria spectrum is brought out very well. Lime added to a mixture of 10 per cent. yttria and 90 per cent. didymium brings out the yttrium spectrum fairly, but the tube soon becomes non-conducting.

Yttrium 5 per cent. and glucinum 95 per cent. gives a bright phosphorescence, but the definition of the spectrum lines of yttria is bad.

Yttrium 5 per cent., thallium 95 per cent.—No spectrum is given by this mixture, it turns black and refuses to phosphoresce.

Yttrium 5 per cent., tin 95 per cent., phosphoresces faintly, the lines being very indistinct.

Yttrium 5 per cent., titanium 95 per cent., acts like thoria, and the tube becomes non-conducting.

Yttrium 5 per cent., tungsten 95 per cent.—This phosphoresces of a bright yellow colour, the spectrum is brilliant, but the lines are not sharply defined. In the phosphoroscope the colour becomes greenish, and the spectrum shows only the green lines of $G\beta$.

Yttrium 5 per cent., zinc 95 per cent.—The phosphorescence is of a pale yellowish-white, and the spectrum is very brilliant, being equal to that shown by 30 per cent. of yttrium with barium, calcium, magnesium, or strontium. In the phosphoroscope the colour becomes reddish, and the $G\beta$ green line is the first to come. No citron line is seen. If the yttrium contains a trace of samarium, the samarium spectrum, which is scarcely seen under ordinary circumstances, now comes out distinctly.

Zinc sulphate mixed with 95 per cent. of calcium sulphate phosphoresces a bright bluish-green colour; the spectrum contains no bands or lines.

Zinc sulphide (Sidot's hexagonal blende*).—This is the most brilliantly phosphorescent body I have yet met with. In the vacuum tube it begins to phosphoresce at an exhaustion of several inches below

* 'Comptes Rendus,' vol. 62, 1886, pp. 999—1001; vol. 63, 1866, pp. 188—189.

a vacuum. At first only a green glow can be seen; as the exhaustion gets better a little blue phosphorescence comes round the edges. At a high exhaustion, on passing the current the green and blue glows are about equal in brightness, but the blue glow vanishes immediately the current stops, while the green glow lasts for an hour or more. In the phosphoroscope the blue glow is only seen at a very high speed, but the green glow is seen at the slowest speed, and the body is almost as bright in the instrument as out of it. Some parts of a crystalline mass of blende which, under the action of radiant matter, leave a glow with a bright blue colour, leave a green residual light when the current ceases; other parts which glow blue become instantly dark on stopping the current.

The different action of calcium, barium, and strontium on the constituents of yttrium is an additional proof, if confirmation be needed, that the bodies I have provisionally called $G\alpha$, $G\beta$, $G\delta$, &c.,* are separate entities. It may be as well here to collect together the evidence on which I rely to support this view. I will take the bodies *seriatim* :—

$G\alpha$.—An earth phosphorescing with a blue light, and showing in the spectroscope a deep blue line, of a mean wave-length 482. This earth occurs in different proportions in purified yttria from different minerals. Samarskite, gadolinite, hiemite, monazite, xenotime, euxenite, and arrhenite contain most $G\alpha$, whilst fluocerite and cerite contained notably less of this constituent. The addition of lime brings out the phosphorescence in $G\alpha$ in advance of that of the other constituents. The behaviour in the phosphoroscope of $G\alpha$ when mixed with the alkaline earths also points to a difference between it and its associates. With lime the blue phosphorescent band of $G\alpha$ comes into view at a very low speed, the order of appearance with a small quantity of lime being $G\beta$, $G\alpha$, $G\delta$, and with a large quantity of lime, $G\delta$, $G\alpha$, $G\beta$. Employing strontia instead of lime, the order of appearance in the phosphoroscope when the quantity of strontia is small is $G\beta$, $G\alpha$, $G\eta$, and when the quantity of strontia is in excess, $G\alpha$, $G\eta$, $G\beta$. Baryta in small quantity brings out the lines in the phosphoroscope in the following order: $G\beta$, $G\alpha$, $G\eta$, but when the baryta is in excess the order is $G\beta$, $G\eta$, $G\alpha$. The chemical position taken up by $G\alpha$ in the fractionation scheme precludes it from being due to the bodies I have called $G\beta$, $G\gamma$, $G\epsilon$, $G\zeta$, $S\gamma$, or $S\delta$. It closely accompanies $G\delta$ (the earth giving the citron line), concentrating at the least basic end, and I have not yet succeeded in effecting a separation of the two. If, therefore, $G\alpha$ is not a separate entity, its blue line must be due to the citron-band-forming body called $G\delta$. The difference between $G\alpha$ and $G\delta$ is brought out in a marked manner by

* 'Roy. Soc. Proc.,' vol. 40, 1886, p. 502.

the phosphoroscope when baryta or strontia is present; the citron line of $G\delta$ being entirely suppressed, while the blue line of $G\alpha$ is brought out with enhanced brilliancy. For these reasons I am inclined to regard $G\alpha$ as a separate body, although the evidence in favour of this view is not so strong as in the case of some of its other associates.

$G\beta$.—An earth phosphorescing with green light, and showing in the spectroscope a close pair of greenish-blue lines of a mean wave-length of 545. This earth can be separated by chemical fractionation from the other constituents of yttrium. It concentrates at the most basic end, and is present in the samarium which invariably makes its appearance at this end of the fractionation of yttrium. It is one of the prominent lines in $Y\alpha$, where also it accompanies some of the samarium lines. $G\beta$, however, is not a constituent of samarium, for it is easy to purify samarium by chemical means so that it does not show a trace of the $G\beta$ green lines, although it is very difficult to get $G\beta$ free from some of the samarium lines. The residual phosphorescence of $G\beta$ is very considerable, and its green lines show first in the phosphoroscope when only yttrium is present. The addition of lime keeps back the glow of $G\beta$, and brings forward that of $G\epsilon$. Strontium and barium act on $G\beta$ very differently to lime. A small quantity of strontium brings forward the residual glow of $G\beta$, whilst in large quantities strontium keeps the phosphorescence of $G\beta$ back to the last.

$G\gamma$.—An earth phosphorescing with a green colour, and showing in the spectroscope a green line having a wave-length of 564. This is one of the least definite of all the supposed new bodies. It appears to be a constituent of samarium, occurring in the fractionation of yttrium among the most basic constituents connecting yttrium and samarium. Its point of maximum intensity is, chemically, very well marked, and is at a different part of the fractionation scheme to those of the other lines of samarium, especially $G\epsilon$. On dilution with lime the phosphorescent line of $G\gamma$ vanishes before that of $G\epsilon$.

$G\delta$.—An earth phosphorescing with a citron-coloured light, and showing in the spectroscope a citron line having a wave-length of 574. $G\delta$ is one of the least basic of all the bodies associated in yttrium, occurring almost at one extremity of the fractionation. It is not very difficult to separate chemically $G\delta$ from all the other accompanying bodies except the one which I have called $G\alpha$ (giving the deep blue line). Not only can $G\delta$ be obtained free from the other four constituents of yttrium, but the body called by M. de Marignac $Y\alpha$ is a proof that the other four components of yttrium can be obtained quite free from $G\delta$. Lime intensifies the phosphorescence of $G\delta$, and deadens that of $G\beta$, while strontium has the opposite action. The behaviour of $G\delta$ in the phosphoroscope, when mixed with lime,

strontia, or baryta, also affords a striking evidence of individuality, line enhancing the residual glow, while strontia and baryta altogether suppress it.

$G\epsilon$.—An earth phosphorescing with a yellow colour, and, in the spectroscope, showing a sharp yellow line having a wave-length of 597. It is seen in the samarium spectrum as a sharp yellow line superposed on a hazy double band. As I have already pointed out, $G\epsilon$ fractionates out high up among the most basic earths, and generally accompanies lanthanum. In the phosphorescent spectrum of lanthanum the line $G\epsilon$ is seen quite free from the lines of other bodies.

$G\zeta$.—An earth phosphorescing with a red light, showing in the spectroscope a red line of wave-length 619. This body is always more plentiful in yttrium obtained from samarskite and cerite than from gadolinite, hielmite, and euxenite, and is almost absent in yttrium from xenotime. $G\zeta$ is of about intermediate basicity. Working with samarskite yttria, $G\zeta$ becomes most brilliant after the line of $G\eta$ has completely disappeared. Further fractionation causes the line of $G\zeta$ to fade out, and the citron and blue lines are then left.

The phosphorescence of $G\zeta$ is developed to a different extent according to the metal with which the yttria is mixed. The order (beginning with the substance having the greatest action) is zirconium, tin, aluminium, bismuth, glucinum.

$G\eta$.—An earth phosphorescing with a deep red light, and showing in the spectroscope a red line having a wave-length of 647. Like its fellow red constituent, $G\eta$ occurs most plentifully in samarskite yttrium, and scarcely at all in yttrium from hielmite, euxenite, and cerite. It is the first of the strictly yttrium constituents to separate out, on fractionation, at the most basic extremity, leaving $G\alpha$, $G\beta$, $G\delta$, and $G\zeta$. In almost all samples of yttria, except when very highly purified, $G\eta$ is seen very brilliantly, and by its side can be detected the faint red band of samarium. In the phosphoroscope the line of $G\eta$ is the last to appear when yttria alone is being observed; strontia and baryta enhance the residual glow of $G\eta$, strontia in moderate quantities bringing it out before that of $G\beta$, while baryta brings it out after $G\beta$.

$S\delta$.—An earth giving in the spectroscope when phosphorescing a very sharp orange line of wave-length 609. I have already* discussed the claims of this earth to be considered a separate entity. It is not present in the rare earths from gadolinite, xenotime, monazite, hielmite, euxenite, and arrhenite; it is present in small quantity in cerite, and somewhat more plentifully in samarskite. In samarskite yttrium it concentrates at a definite part of the fractionation. Its

* 'Roy. Soc. Proc.,' vol. 40, 1886, p. 540.

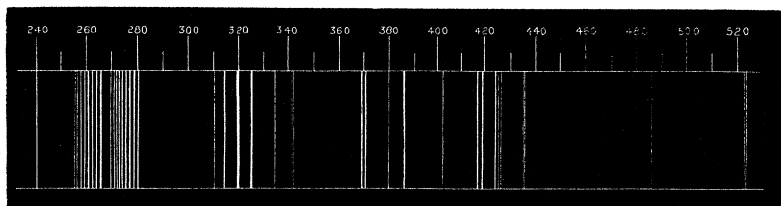
sharp orange line is not strong enough to be seen in the phosphoroscope. A little calcium entirely suppresses the orange line, while samarium or yttrium seems to intensify it.

In addition to the above earths, it is not improbable that the sharp green line ($1/\lambda^2 325$) mentioned under the heading "Yttrium" may be caused by still another earth.

The brilliant and characteristic spark spectra yielded when certain elements are volatilised and rendered incandescent by the spark from a powerful induction coil are relied on by chemists as an indisputable proof of the identity of such elements. Bearing this in mind I have endeavoured to ascertain how these yttrium constituents would behave in respect to the spark spectrum. Do the definite system of lines in the old yttrium spark spectrum belong to one constituent only, or are the yttrium lines broken up and distributed among the different bodies I have designated as $G\alpha$, $G\beta$, &c.? Also do the other constituents possess special spark spectra of their own? Very careful and long-continued experiments have shown me that neither of these hypothetical cases occur.

The spark spectrum given by old yttrium is shown in the drawing (fig. 5). It is chiefly characterised by two very strong groups of lines in the red and orange. I now take the earth $G\delta$. This occurs

FIG. 5.



near one end of the fractioning, and not only differs from the parent yttrium in its phosphorescent spectrum, but by virtue of the process adopted for its isolation it must likewise differ in its chemical properties. On examining its spark spectrum I see absolutely no difference between this spectrum and the one given by old yttrium.

I now pass to the other end of the fractionation of yttrium, where occurs a concentration of a body giving a totally different phosphorescent spectrum to the one at the first end. And it also differs chemically from old yttrium, and in a more marked manner from its brother, $G\delta$, at the other extremity of the fractionation. Here again its spark spectrum is perfectly identical both with old yttrium and with $G\delta$, and however closely I examine these three spectra in my laboratory, the whole system of lines is still identical.

Respecting the theoretical considerations involved in these results, I see two possible explanations of the facts brought forward. According to one hypothesis, research has somewhat enlarged the field lying between the indications given by ordinary coarse chemistry and the searching scrutiny of the prism. Our notions of a chemical element have expanded. Hitherto the molecule has been regarded as an aggregate of two or more atoms, and no account has been taken of the architectural design on which these atoms have been joined. We may consider that the structure of a chemical element is more complicated than has hitherto been supposed. Between the molecules we are accustomed to deal with in chemical reactions and the ultimate atoms, come smaller molecules or aggregates of physical atoms; these sub-molecules differ one from the other, according to the position they occupied in the yttrium edifice.

An alternative theory commends itself to chemists, to the effect that the various bodies discussed above are new chemical elements differing from yttrium and samarium in basic powers and several other chemical and physical properties, but not sufficiently to enable us to effect any but a slight separation. One of these bodies, $G\delta$, gives the phosphorescent citron line, and also the brilliant electric spectrum. The other seven do not give electric spectra which can be recognised in the presence of a small quantity of $G\delta$, whilst the electric spectrum of $G\delta$ is so sensitive that it shines out in undiminished brilliancy even when the quantity present is extremely minute. In the process of fractionation, $G\alpha$, $G\beta$, $G\delta$, &c., are spread out and more or less separated from one another, yet the separation is imperfect at the best, and at any part there is enough $G\delta$ to reveal its presence by the sensitive electric spark test. The arguments in favour of each theory are strong and pretty evenly balanced. The compound molecule explanation is a good working hypothesis, which I think may account for the facts, while it does not postulate the rather heroic alternative of calling into existence eight or nine new elements to explain the phenomena. However, I submit it only as an hypothesis. If further research shows the new element theory is more reasonable, I shall be the first person to accept it.

Neither of these theories agrees with that of M. Lecoq de Boisbaudran, who also has worked on these earths for some time. He considers that what I have called yttrium is a true element, giving a characteristic spark spectrum, but not giving a phosphorescent spectrum *in vacuo*. The bodies giving the phosphorescent spectra he considers to be impurities in yttrium. These he says are two in number, and he has provisionally named them $Z\alpha$ and $Z\beta$. By a method of his own, differing from mine, M. de Boisbaudran obtains fluorescent spectra of these bodies; but their fluorescent bands are extremely hazy and faint, rendering identification difficult. Some

of them fall near lines in the spectra of my $G\beta$ and $G\delta$. At first sight it might appear that his and my spectra were due to the same bodies, but according to M. de Boisbaudran, the chemical properties of the earths producing them are widely distinct. These giving phosphorescent lines by my method occur at the yttrium extremity of the fractionation, where his fluorescent bands are scarcely shown at all; whilst his fluorescent phenomena are at their maximum quite at the terbium end of the fractionation, where no yttrium can be detected even by the direct spark, and where my phosphorescent lines are almost absent.

Presents, February 17, 1887.

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FIG. 1, A.

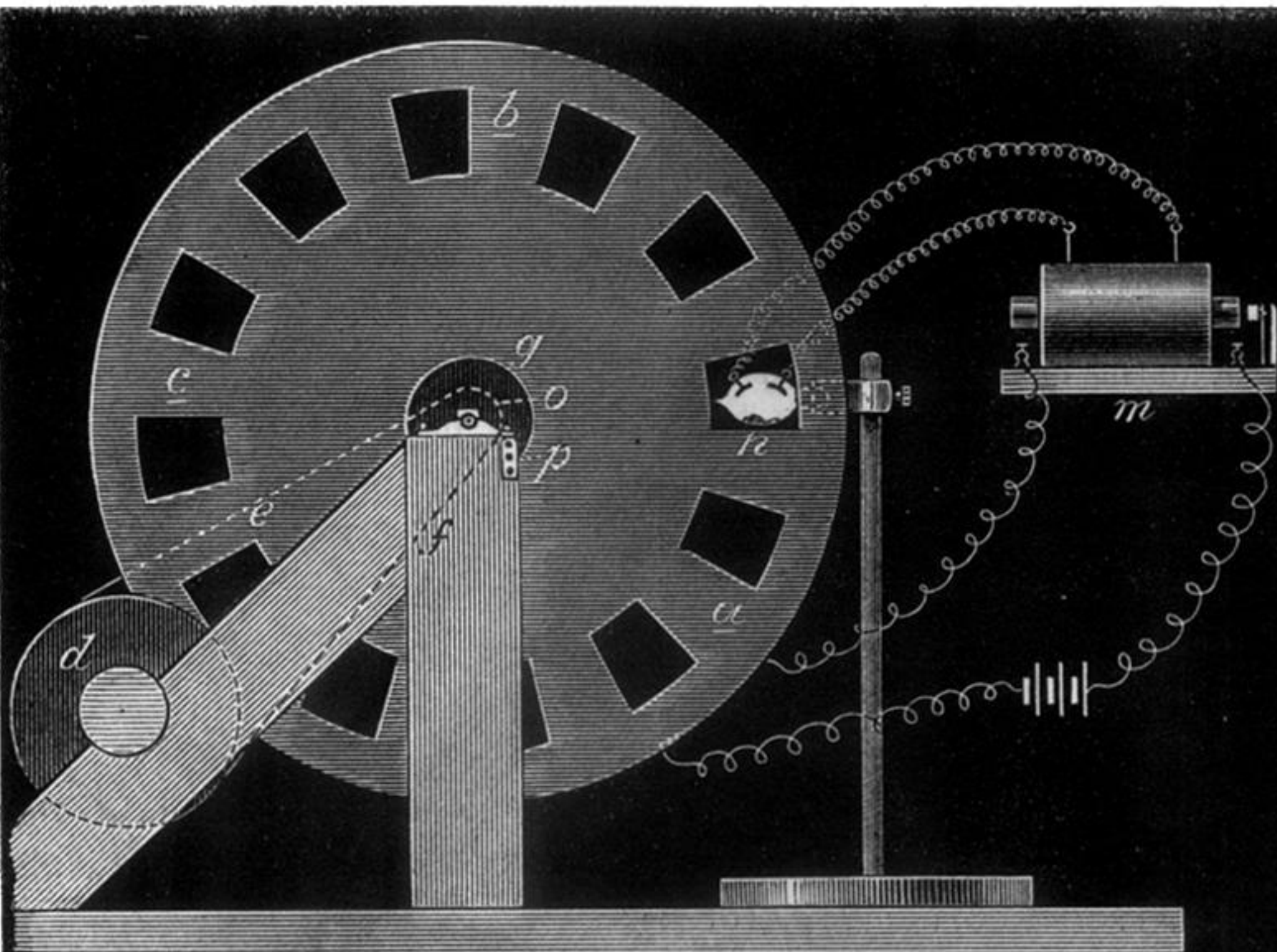
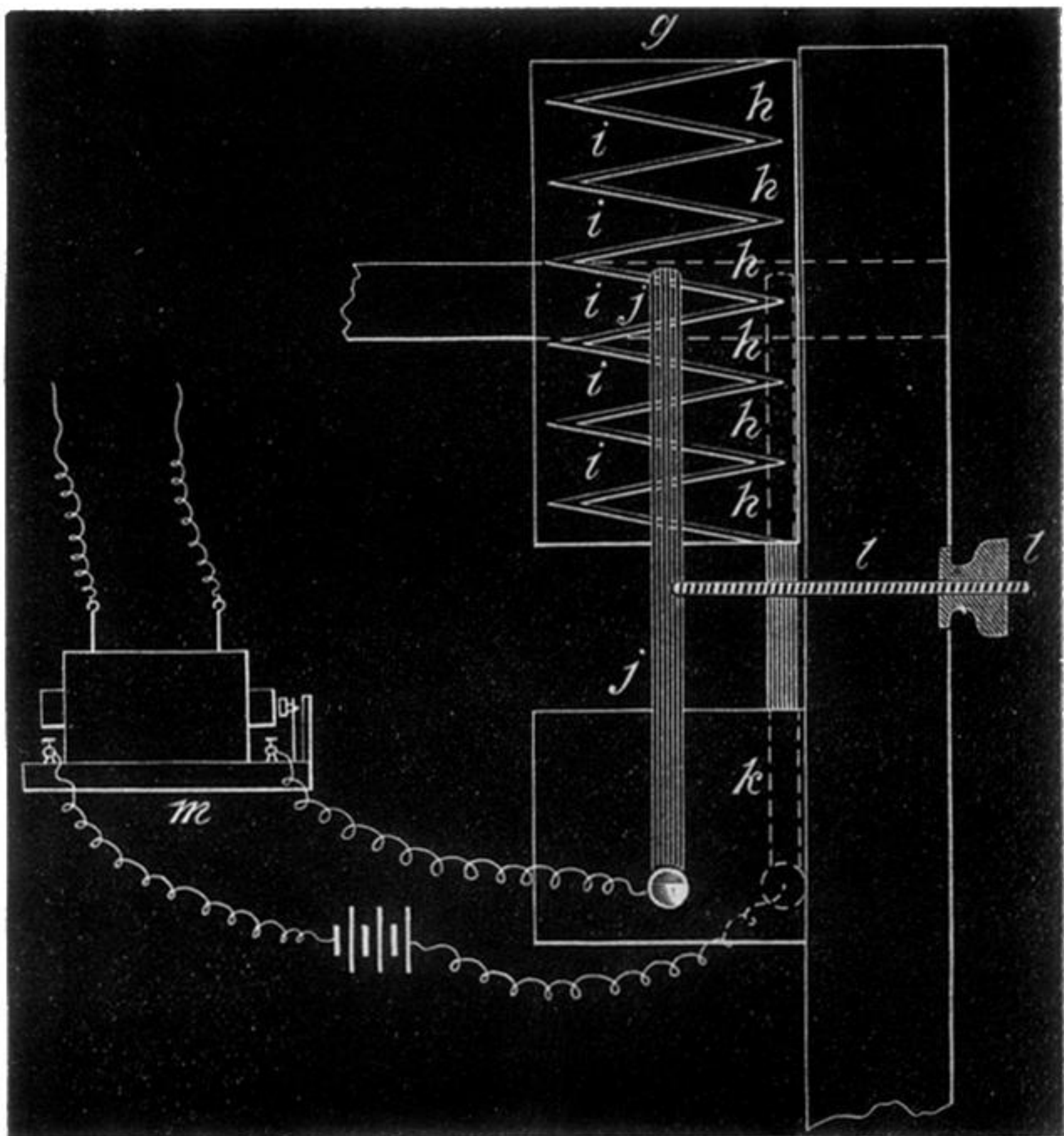


FIG. 1, B.



30 240 50 260 70 280 90 300 10 320 30 340 50 360 70 380 90 400 10 420 30

C

D

E

b

F

Fig. 2. Yttria

Fig. 3. Y_a (Gadolinia)

Fig. 4. Yttria 61 Samaria 39.

FIG. 5.

